CASE VII. *Multiple Bee-stings of the Scalp, accompanied by severe constitutional symptoms, and followed by Erysipelatous Inflammation of the Head and Face; Recovery.*—O. G. R., a robust young man, aged 22, a farm-labourer, while hiving a swarm of bees on the limb of an apple tree, was stung by them several times in the forehead. The injured parts immediately became the seat of intense burning pain and began to swell. The tumefaction increased rapidly and extended widely. The inflammation was diffuse in character, the skin dark red and hot. It soon extended to his face, and in a few hours his eyes were closed from tumefaction of the lids, his countenance became much distorted, and his ears involved in the morbid process. The stings, however, continued to be the principal seat of the pain, which remained severe and burning in character. The stingers had been left in the wounds by the insects.

He also exhibited decided evidences of constitutional disturbance. Soon after being stung he complained of feeling weak, faint, and chilly, and also vomited. This depressed condition of his system was followed by considerable reaction of a sthenic character. He then became feverish, thirsty, and restless. On the second day the erysipelatous inflammation of his head and face began to decline, and in a few days thereafter entirely disappeared, tarrying longest, however, at the wounds.

The remedial measures employed were of a simple nature. The stingers were extracted with tweezers, and then the affected parts were kept wet with a cold lotion which consisted of spirits of camphor and water. He kept his bed, and a dose of magnesium sulph. was administered after the fever came on.

In regard to the treatment of the stings of bees and other venomous insects the best plan is, after extracting the stingers, to apply liquor ammoniæ freely to the injured parts, with a view to decompose the venom and thus render it harmless. When the prostration due to absorption of the poison into the system is considerable, a few drops of the ammonia mixed in water should be administered by the mouth; and when it is very great the ammonia should be administered hypodermically, in sufficiently large doses to prevent the occurrence of cardiac paralysis. The diffuse inflammation of the injured parts generally requires the application of cold lotions, of which the lead and opium wash is one of the best.

46 WASHINGTON SQUARE, January 1, 1879.

ARTICLE II.

EXPERIMENTS AND REFLECTIONS UPON ANIMAL HEAT.

By AUSTIN FLINT, Jr., M.D., Professor of Physiology and Physiological Anatomy in the Bellevue Hospital Medical College, New York, etc. etc.

HAVING had occasion recently to study the question of the force-value of food in connection with investigations into the source of muscular power, and the laws of conservation of force as applied to the theories of muscular action, I became much interested in the subject of animal heat. The theories of the mechanism of the production of heat by animals have lately assumed a very positive and definite form; and certain statements are now presented as facts, which appear to be entirely satisfactory to many physiologists. The question involved is one of great pathological as well as physiological importance. It is well known that the temperature of the deeper parts of the body, which are little exposed to external refrigerating influences, does not vary in health more than two or three degrees Fahrenheit, and that this temperature is, to a great extent, independent of that of the surrounding atmosphere. When, from any cause, whether it be external or internal, there is a tendency to an elevation of the animal temperature, the heat is kept at the normal standard mainly by evaporation from the surface of the skin. There is, indeed, a constant generation of heat within the body, which is sufficient to maintain the animal temperature and to compensate the loss of heat from the surface. It is evident that this internal production of heat is connected with the general process of nutrition, and that it must involve changes in the form of matter within the animal organism. Carbonic acid is constantly discharged from the body, and this is one of the most important products connected with changes in matters, which produce heat. The body as constantly consumes oxygen, and oxidation is a process connected with most of the changes involved in calorification.

It is evident that, in normal nutrition by food, the heat of the body must be maintained by changes which take place, either directly in the blood or indirectly in the tissues, in the alimentary matters, and that these changes involve oxidation to a very considerable extent. Under ordinary conditions of nutrition, it is assumed that the food furnishes all the material for maintaining the heat of the body and for the development of force in work such as the muscular work of respiration and circulation and general muscular effort. If no food be taken for a certain time, the heat of the body must be maintained and the work must be accomplished at the expense of the substance of the body itself, and the individual loses weight.

To furnish a positive scientific basis for the views above expressed, physiologists have burned various articles of food in oxygen and have thus calculated their heat-value. This has been expressed in what are called heat-units, the English value of a heat-unit being the amount required to raise one pound of water one degree of the Fahrenheit scale. It is also calculated that one heat-unit converted into force will raise 772 pounds one foot high, or is equal to 772 foot-pounds. The theory of the heat-value and the force-value of food, based upon these premises, is the following:

The heat-value of food may be expressed in a definite number of heat-units. A certain proportion of these heat-units serves to maintain the standard animal temperature. A certain proportion is converted into the force used in the muscular work of respiration and circulation. A certain proportion is used in ordinary muscular work. If the supply of food be in excess of these various requirements, a certain part of it is not used and the body may gain in weight. If the supply of food, however, be below the demands of the system, a part of the tissues of the body itself is consumed, and there must be a loss of weight.

There is no objection to such a theory as the one just stated on the ground of want of simplicity or comprehensiveness; but it must be admitted that many of its essential propositions are of necessity wanting in accuracy. Suppose that it be assumed as true, for the sake of argument, that one heat-unit is capable of being transformed in the body into 772 foot-pounds of force. It must be proven that a certain definite amount of heat is produced by the body. A reasonably accurate estimate must be made of the force consumed in the muscular work of respiration and circulation, expressed in foot-pounds. The general muscular work of the body must also be computed in foot-pounds.

I do not propose to discuss, in this connection, the last two propositions, and I think I have shown, in another place, the enormous errors that exist in the calculations by which the muscular work of the body has been reduced to foot-pounds.[1]

I shall discuss, in this essay, the estimated heat-value of certain articles of food and experiments made with reference to the heat-units actually produced by the body. I shall then give an account of observations made upon my own person, in which I endeavoured to ascertain something definite with regard to the relations between the heat estimated as produced by the body, the loss of weight of the body during one day's abstinence from food, and the estimated heat-value of a carefully weighed quantity of food taken during one day.

Estimated Heat-value of certain Articles of Food.—Following the observations made by Fick and Wislicenus, in 1866, by which these observers attempted to show that nearly all the force resulting from muscular action is due to the oxidation of non-nitrogenized matters, physiologists have estimated the heat-value and the force-value of different articles of food. They have reasoned that the food, by its oxidation in the body, is capable of producing a certain amount of heat and that a part of this heat is converted into force. A method now employed to calculate the heat produced is to subtract the daily mechanical force expended from the total force-value of the food, the result giving the daily formation of heat. A recent writer estimates in this way that "between one-fifth and one-sixth of the total income is expended as muscular labour, the remaining four-fifths or five-sixths leaving the body in the form of heat."[2] The reduction of heat-units to units of force is made in accordance with Joule's formula, that one heat-unit (the heat required to raise the temperature of one pound of water one degree Fahrenheit) is equal to 772 foot-pounds, or will raise 772 pounds one foot high.

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[1] A. Flint, Jr., Source of Muscular Power, New York, 1878.

[2] Foster, Text-Book of Physiology, London, 1877, p. 323.

In 1866, Frankland made a number of calculations of the heat-units and the estimated force-value of various articles of food[1] which are now accepted and used by most writers upon subjects connected with the theories of animal heat and the source of muscular power. The experiments upon which these calculations are based were made with great care and exactness. The following quotation gives, in a few words, the method employed:

> "In order to estimate the amount of actual energy generated by the oxidation of a given amount of muscle in the body, it is necessary to determine, first, the amount of actual energy generated by the combustion of that amount of muscle in oxygen, and then to deduct from the number thus obtained the amount of energy still remaining in the products of oxidation of this quantity of muscle which leave the body. Of these products, urea and uric and hippuric acids are the only ones in appreciable quantity which still retain potential energy on leaving the body, and of these the two latter are excreted in such small proportions that they may be considered as urea without introducing any material error into the results.
>
> "These determinations were made in Lewis Thompson's calorimeter, which consists of a copper tube to contain a mixture of chlorate of potash with the combustible substance, and which can be inclosed in a kind of diving-bell, also of copper, and so lowered to the bottom of a suitable vessel containing a known quantity (2 litres) of water. The determinations were made with this instrument in the following manner: 19.5 grams of chlorate of potash, to which about $\frac{1}{8}$th of peroxide of manganese was added, was intimately mixed with a known weight (generally about 2 grams) of the substance whose potential energy was to be determined, and the mixture being placed in the copper tube above mentioned, a small piece of cotton thread, previously steeped in chlorate of potash and dried, was inserted in the mixture. The temperature of the water in the calorimeter was now carefully ascertained by a delicate thermometer, and the end of the cotton thread being ignited, the tube with its contents was placed in the copper bell and lowered to the bottom of the water. As soon as the combustion reached the mixture a stream of gases issued from numerous small openings at the lower edge of the bell and rose to the surface of the water, a height of about ten inches.
>
> "At the termination of the deflagration, the water was allowed free access to the interior of the bell, by opening a stopcock connected with the bell by a small tube rising above the surface of the water in the calorimeter. The gases in the interior of the bell were thus displaced by the incumbent column of water, and by moving the bell up and down repeatedly a perfect equilibrium of temperature throughout the entire mass of water was quickly established. The temperature of the water was again carefully observed, and the difference between this and the previous observation determines the calorific power or potential energy, expressed as heat, of the substance consumed.
>
> "The value thus obtained is, however, subject to the following corrections:—
>
> "1. The amount of heat absorbed by the calorimeter and apparatus employed, *to be added.*
>
> "2. The amount of heat carried away by the escaping gases, after issuing from the water, *to be added.*
>
> "3. The amount of heat due to the decomposition of chlorate of potash employed, *to be deducted.*
>
> "4. The amount of heat equivalent to the work performed by the gases generated in overcoming the pressure of the atmosphere, *to be added.*"[2]

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[1] Frankland, On the Origin of Muscular Power.—Philosophical Magazine, London, 1866, vol. xxxiii., p. 182 *et seq.*

[2] Frankland, in Bence Jones, Croonian Lectures on Matter and Force, London, 1868, p. 141 *et seq.*

It is evident that the determinations made in the manner above described, care being taken to make the corrections indicated (which can be done without difficulty), give the amount of heat produced by the simple burning of the articles employed. As regards the heat produced by the oxidation of these substances in the body, if it be assumed that the same quantity of heat is produced by the oxidation, under all circumstances, of a definite amount of oxidizable matter, it is necessary simply to deduct from the heat-value of articles of food the heat-value remaining in the certain parts of the food which pass out of the body in an unoxidized state. It was in this way that Frankland arrived at a determination of the heat-value of articles of food oxidized in the body.

Estimated amount of Heat actually produced by the Body.—In January, 1872, Senator made an elaborate series of observations upon dogs, in which he attempted to ascertain the actual quantity of heat produced by the body per hour per kilogramme of body-weight. The principle upon which these observations were made was essentially the same as that which underlies the experiments of Frankland upon the amount of heat produced by the oxidation of alimentary matters. The animals experimented upon by Senator were inclosed in a copper cage which corresponds to the bell of copper in Thompson's calorimeter. The cage was supplied with a current of air, the temperature of which was carefully noted as it entered and passed out. The apparatus was immersed in a known volume of water, the temperature of which was noted at the beginning and at the close of each observation. The so-called combustion processes taking place in the body of the animals correspond to the deflagration of the alimentary substances in Frankland's experiments. The variations in the temperature of the animals and the loss of heat by the cooling of the apparatus itself were noted and used as corrections. In five experiments, the animals remaining in the apparatus for one hour in each observation, the gain in temperature of the water, all the necessary corrections being made, gave an average of 12.63 heat-units for an average weight of the animals of 5.383 kilogrammes;[1] that is to say, the increase in temperature of the water surrounding the cage in which the animals were inclosed was equal to 12.63° C. for each kilogramme of water. Reducing these results to the heat-units produced per kilogramme of weight of the body of the animal, there was a production of 2.34 heat-units per kilogramme of weight. The heat-unit calculated by Senator represents the raising of one kilogramme of water one degree Centigrade. One degree Centigrade equals 1.8° Fahrenheit. Reducing the heat-units, therefore, to the Fahrenheit scale, we should have the 2.34 heat-units equal to 4.212 heat-units Fahrenheit. As the heat-units used by Senator are per kilogramme of weight of the body and per kilogramme of water, the figures are the same when we make the calculation for a pound of water and a pound weight of the body. Reduced to heat-units representing the raising of one pound of water one degree Fahrenheit for each pound of weight of the body, we have, as the result of Senator's observations, a production of 4.212 heat-units per hour per pound of body-weight.

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[1] Senator, Untersuchungen über die Wärmebildung und den Stoffwechsel.—Archiv für Anatomie, Physiologie, und Wissenschaftliche Medicin, Leipzig, 1872, S. 20. In Senator's experiments, estimates were made of the exhalation of carbonic acid during each observation which I do not introduce into the discussion.

In December, 1872, Dr. John C. Draper, of New York, made a series of observations upon his own person, similar to those of Senator upon dogs. In these observations, he lay for one hour in a bath of a known volume of water. After making the necessary correction for the absorption of heat from the atmosphere by the water, which was $\frac{1}{2}$° Fahr., he ascertained that he warmed "seven and one-half cubic feet of water two degrees in one hour." He estimated the volume of the body at three cubic feet, from which he calculated that "enough heat is evolved in the course of one hour to warm the body itself about five degrees of Fahrenheit's scale."[1] Two experiments made in this way on two successive days gave identical results. In both of these experiments, the temperature in the mouth on entering the bath was 99° Fahr. After one hour in the bath, the temperature in the mouth was 98° Fahr., showing a reduction in the temperature of the body of one degree. The temperature of the water at the beginning of the experiment was 74°. I shall assume, therefore—though this correction was not made by Draper—that, of the five degrees calculated as gained by three cubic feet of water and derived from the body, one degree was due to the cooling of the body, leaving four degrees of heat actually produced by the body in the hour. A given weight of the body being capable of warming an equal weight of water four degrees Fahrenheit in one hour, it follows that the body produces four heat-units per pound per hour, the heat-unit representing the raising of one pound of water one degree Fahrenheit.

The results obtained by Draper correspond very closely with those given by Senator. There is no reason to doubt the accuracy of the observations of either of these experimenters. It may be objected to Draper's experiments that the body in a bath is not under conditions absolutely physiological; but the condition of the dogs in Senator's experiments was not so abnormal as to seriously impair the value of his conclusions. In the applications which I shall make of the results of these experiments to my own observations, I shall assume that the body produces four heat-units per pound weight per hour.

In the same way it may be assumed that there is no reason to doubt the accuracy of Frankland's observations showing the heat-units produced by the oxidation of various articles of food. I shall therefore regard the determinations made by Frankland as definite propositions in the discussion which is to follow.

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[1] Draper, The Heat Produced in the Body, and the Effects of Exposure to Cold.—American Journal of Science and Arts, New Haven, December, 1872.

Conversion of Heat into Force in the Body.—In 1842, Dr. J. R. Mayer published an essay on the forces of inorganic nature, which is regarded as the starting point of the modern theories of the correllation and conservation of forces. These theories, which were at first applied to the forces developed by chemical changes in inorganic matters, have recently been applied to the production of heat and the development of force in animal bodies. It is not surprising that the theory alluded to should be thus applied. Physiologists have long been seeking for an expression of the phenomena of animal heat and force in definite quantities, and they have endeavoured to show that these phenomena are in accordance with certain laws which are applicable to the inorganic world. With our present knowledge, the idea of the actual generation or the total destruction of a single atom of matter is inconceivable. Matter changes its form, its characters, and the arrangement of its elementary constituents; but matter itself is indestructible. It is impossible, also, to conceive of force without matter. Philosophers regarding matter as indestructible, the idea of the indestructibility of force naturally follows; and, as matter undergoes changes by different arrangements of chemical elements, may there not be different kinds of manifestation of force which are interchangeable and interconvertible? The first step in the formulization of such an idea is the establishment of a unit of force which can be used to represent all dynamic manifestations; and the simplest way in which this can be expressed or defined is to measure all force by the power required to raise a certain weight a certain distance above the surface of the earth. We therefore express our idea of the quantity of any force in the raising of a given number of pounds to the height of a certain number of feet.

It is evident that the heat developed by chemical changes may be used in the production of power. We are in the habit of measuring heat by the expansion of some substance, such as mercury, and this is reduced to the degrees of an established scale. English writers have fixed upon a definite unit of heat, which is the amount required to raise one pound of water one degree in the Fahrenheit scale.

We thus have two fixed quantities to give form to our ideas of heat and force; a heat-unit, which equals one pound of water raised one degree Fahrenheit, and a unit of force, which equals one pound weight raised one foot high.

The line of reasoning adopted by Mayer is briefly the following:[1] An effect has a cause. Force is a cause which may produce a certain effect. A body cannot fall to the earth without having been raised to the height from which it falls. The cause *c* has an effect *e*, which effect may itself act as a cause and produce a second effect *f*.

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[1] Mayer. The Forces of Inorganic Nature.—Correllation and Conservation of Forces, New York, 1868, p. 251 *et seq.*

> "If the given cause *c* has produced an effect *e* equal to itself, it has in that very act ceased to be: *c* has become *e*; if, after the production of *e*, *c* still remained in whole or in part, there must be still further effects corresponding to this remaining cause: the total effect of *c* would thus be $> e$, which would be contrary to the supposition $c = e$. Accordingly, since *c* becomes *e*, and *e* becomes *f*, etc., we must regard these various magnitudes as different forms under which one and the same object makes its appearance. This capability of assuming various forms is the second essential property of all causes. Taking both properties together, we may say, causes are (quantitatively) *indestructible* and (qualitatively) *convertible* objects."

The line of reasoning followed by Mayer leads him to conclude that, the force exerted by a falling body ("falling force") being equal to the force which has raised the body to the height from which it has fallen, this "falling force" itself acts as a cause and produces an effect. The first cause *c* equals the effect *e*, and the effect *e*, acting as a cause, equals the second effect *f*. $c = e = f$. Consequently, $f = c$. The effect *f* is expressed in an elevation of temperature. The first cause *c* finally produces *f*; and, as the falling of a definite weight a certain distance produces a definite amount of heat, the heat thus produced is equal to the force required to raise the weight to the height from which it has fallen. The following are the conclusions arrived at by Mayer by this course ot reasoning.

> "By applying the principles that have been set forth to the relations subsisting between the temperature and the volume of gases, we find that the sinking of a mercury column by which a gas is compressed is equivalent to the quantity of heat set free by the compression; and hence it follows, the ratio between the capacity for heat of air under constant pressure and its capacity under constant volume being taken as $= 1.421$, that the warming of a given weight of water from 0° to 1° C. corresponds to a fall of an equal weight from the height of about 365 metres.[1] If we compare with this result the working of our best steam engines, we see how small a part only of the heat applied under the boiler is really transformed into motion or the raising of weights; and this may serve as justification for the attempts at the profitable production of motion by some other method than the expenditure of the chemical difference between carbon and oxygen—more particularly by the transformation into motion of electricity obtained by chemical means."

In an essay upon the "Correlation of Physical Forces," by Grove, is a very clear and succinct account of the experiments of Joule,[2] whose results are those most generally adopted and used at the present day:

> "Mr. Joule has made a great number of experiments for the purpose of ascertaining what quantity of heat is produced by a given mechanical action. His

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[1] The above reduced to a degree of Fahrenheit and to feet gives the following: One heat-unit Fahrenheit, or one pound of water raised one degree Fahrenheit, equals one pound weight raised to the height of 665 feet, or 665 foot-pounds.

The following note is added by the translator of Mayer's essay:

"When the corrected specific heat of air is introduced into the calculation this number is increased, and agrees then with the experimental determinations of Mr. Joule."

[2] Joule's original essay is in the Philosophical Transactions, 1850, p. 61, and is entitled "On the Mechanical Equivalent of Heat."

> mode of experimenting is as follows: An apparatus formed of floats or paddles of brass or iron is made to rotate in a bath of water or mercury. The power which gives rise to this rotation is a weight raised like a clock-weight to a certain height; this by acting during its fall on a spindle and pulley communicates motion to the paddle-wheel, the water or mercury serving as a friction medium and calorimeter; and the heat is measured by a delicate mercurial thermometer. The results of his experiments he considers prove that a fall of 772 pounds through a space of one foot is able to raise the temperature of one pound of water through one degree of Fahrenheit's thermometer. Mr. Joule's experiments are of extreme delicacy—he tabulates to the thousandth part of a degree of Fahrenheit, and a large number of his thermometric data are comprehended within the limits of a single degree. Other experimenters have given very different numerical results, but the general opinion seems to be that the numbers given by Mr. Joule are the nearest approximation to the truth yet obtained."[1]

I have thus given as plain a statement as I could make of the experiments upon which the prevailing theories of the mechanical equivalent of heat are based. The experimental fact involved is the production of heat by force. Algebraically, the equations seem unquestionable. Cause = effect; effect acting as a second cause = a second effect, which is heat; consequently the first cause, which is a definite amount of force, = the second effect, which is a definite amount of heat, and conversely the heat = the force. The experimental demonstration is the production of a certain quantity of heat by falling force, but never the production of the same amount of force by the heat. We can readily understand how there must be, in machinery constructed to produce force by heat, as in a steam-engine, such a waste of heat as to actually give much less useful force than is really equivalent to the heat employed. Viewed in this way, the question rests within the province of pure physics; but when the law of the correlation and conservation of forces is applied to animal mechanics, it is not difficult to see that the argument is entirely one-sided. The operations involved in the theory under consideration are simply two; viz., the production of animal heat and muscular force, the latter including the force used in circulation and in the movements of respiration. In animal mechanics, heat is never produced by force, but it is the theory that force results from a transformation of the heat remaining after sufficient heat has been produced to keep up the constant animal temperature. According to the present theory, physiologists must always reason in one direction, from the transformation of heat into force, while the physical basis of the theory consists of experiments in an opposite direction, the transformation of force into heat. Looking at the question in its relations to physiology, while I cannot say that, in an equation, if $a = b$, the converse, $b = a$, is not a self-evident proposition, I am not prepared to admit, without some experimental proof, the theory that one heat-unit produced in the animal body is equivalent to 772 foot-pounds of force. I fully appreciate the seeming temerity of an expression of want of perfect faith in the doctrine of the convertibility of a certain quantity of heat into a definite quantity of force in animal bodies. It is enough to say that this dogma is accepted by Helmholtz, Faraday, Liebig, Carpenter, and, indeed, by nearly all modern philosophers. But, will this theory accord with all established physiological facts? This is the question that I propose to discuss, carefully considering the experimental basis of the facts that I shall bring forward, and allowing, in my discussion of these facts, for all elements of possible error and inaccuracy. The following propositions, which I make in advance of my discussion, I shall attempt to sustain by experiments quite as positive in their results as those of Mayer and of Joule:

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[1] Grove, Correllation of Physical Forces.—The Correllation and Conservation of Forces, New York, 1868, p. 33.

1. While experiments have shown that the fall of 772 pounds through a distance of one foot, or the fall of one pound through a distance of 772 feet, will produce a quantity of heat that will raise the temperature or one pound of water one degree Fahrenheit, there is no positive experimental proof that such a quantity of heat will raise 772 pounds one foot, or one pound 772 feet.

2. The application to animal physiology of the law that one heat-unit is equal to 772 pounds of force is by no means a logical necessity.. It is not adequately supported by experimental facts, partly for the reason that there are no accurate formulæ which will enable us to express the force used in circulation, respiration, and general muscular effort in definite units such as foot-pounds.

The experiments of Frankland, which I have already discussed, show that certain articles of food, when oxidized, produce a certain quantity of heat. It may be assumed that the amount of heat thus produced will always be the same whether the oxidation be slow or rapid. Animal heat and the force exerted by the body must be derived, directly or indirectly, from food. The quantity of food taken within a certain time can be measured, and the heat-value of such food may be determined. If the food taken can be shown to possess a heat-value which is manifestly in excess of the total ascertainable heat and force developed in the body, we can understand how a certain amount may pass away in such a manner that we cannot with certainty determine how it is lost. Experimental methods in physiology are not so exact as to enable us to follow all the changes which take place in the body, as is well known. But if, on the other hand, the estimated heat-value of food should fall far short of accounting for the heat and force generated in the body, there would seem to be a fatal error either in the law or in its application.

Experiments have been made by precisely the same methods as those by which the heat-value of articles of food has been established, showing that a warm-blooded animal or a man produces a definite amount of heat per hour per pound weight of the body. These experiments I have already discussed. There is no more reason to doubt their accuracy than there is to question the results of the experiments of Frankland upon the heat-value of articles of food. In order to show that the application of the law of the relations between heat and force to animal mechanics is correct and that the law itself is correct, we must, as a logical necessity, be able to account for the heat and force developed in animal bodies by the heat-value of food, or of body-weight consumed, when the food is insufficient. If we have correctly estimated the heat-value of food, if we have also correctly estimated the heat and force developed in the body, there must be an error in the calculated relations between heat and force, if physiological facts do not sustain our theory. A serious defect in the theory that a certain amount of heat is equal to a certain amount of force is that no one has been able to show the actual conversion of one heat-unit into any number approaching that of 772 foot-pounds of force.

Observation 1.—In 1870, I had occasion to note the work, the quantity of food taken, and various other conditions, in a healthy man for several consecutive days. The observations were made at that time with another object in view; but the data obtained will serve in the present argument. I shall here make use of the estimates made for five consecutive days.

During the five days, the total amount of nitrogen in the food was 1173.82 grains. It is estimated by Dr. Pavy,[1] according to the observations of Frankland, that one ounce (437.5 grains) of dry albuminous matter, as consumed within the body, is equal to 165.20 foot-tons of force. Dr. Pavy computes, from Mulder's analysis, that 15.5 is the percentage of nitrogen in dry albuminous matter. According to this computation, 1173.82 grains of nitrogen represent 7573.03 grains, or 17.31 ounces of dry albuminous matter. During these five days, there was a loss of body-weight of 3.45 pounds. The subject of the experiment walked 317½ miles in the five days, and, at the beginning of the walk, had no appreciable fat. I therefore estimated the loss of weight as muscular tissue and calculated it as equal to 724.5 grains of nitrogen, equivalent to 4674.20 grains, or 10.68 ounces of dry albuminous matter.[2] The total force-value, then, of nitrogenous food and of loss of body weight (27.99 ounces of dry albuminous matter) was 4623.95 foot-tons, or 10,357,648.00 foot-pounds, equal to 13,416.64 heat-units.

I carefully estimated, for the five days, the heat-value of the non-nitrogenized food (milk, bread, oatmeal, potatoes, butter, and sugar). The heat-value of this food, calculated from Frankland's tables, amounted to 19,521.41 heat-units.

The following gives the total heat-value of the food and loss of body weight for five days:—

	Heat-units.
Nitrogenized food and loss of body weight	13,416.64
Non-nitrogenized food	19,521.41
Total sources of heat give	32,938.05

The observations of Senator upon dogs and those of Draper upon his own person show that the actual quantity of heat produced by the body is equal to at least four degrees Fahrenheit per pound weight per hour, which gives ninety-six degrees per pound weight for twenty-four hours. The subject of my observations had an average weight, for five days, of 115½ pounds. He consequently produced 11,088 heat-units in twenty-four hours, and 55,440 heat-units in the five days. The estimate of four degrees per pound per hour is for perfect repose. If this estimate be correct for repose, the subject of my experiment must have produced much more heat during the exertion of walking 317½ miles in five days. Taking the estimate of four degrees, however, we have the following:—

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[1] The Lancet, Dec. 16, 1876, p. 849.

[2] According to Payen, lean meat, uncooked, or muscular tissue, contains three per cent. of nitrogen. (Payen, Substances alimentaires, Paris, 1865, p. 488.)

Heat-units produced by the body in five days . . .	55,440.00
Heat-value, in heat-units, of food and loss of body weight .	32,938.05
Heat-units unaccounted for	22,501.95

In the above calculation, no account is taken of the force exerted in walking 317½ miles or of the force employed in circulation and respiration. The estimates of the amount of force used in circulation and respiration are of necessity merely approximative. According to Letheby, it amounts to about 600,000 foot-pounds per day,[1] or 3,000,000 foot-pounds in five days, which equal 3886.00 heat-units. It is even more difficult still to estimate the force used in walking 317½ miles. An estimate has been made, however, of the force used in walking on a level, by Prof. Haughton. This estimate is that the work accomplished is equal to raising one-twentieth of the weight of the body through the distance walked, assuming the rate of speed to be three miles per hour.[2] For sake of argument I shall use this estimate, although I have little confidence in its accuracy, and the rate of speed in walking the 317½ miles was between four and one-half and five miles per hour instead of three miles. The force, then, in walking 317½ miles was equal to 4321.33 foot-tons,[3] or 9,679,779.20 foot-pounds, equivalent to 12,538.57 heat-units. Taking all of these estimates, the total heat-units expended in five days would be as follows:

Heat-units produced (animal heat)	55,440.00
Heat-units converted into force, expended in walking 317½ miles (estimated)	12,538.57
Heat-units converted into force expended in circulation and respiration (estimated)	3,886.00
Total expended in five days	71,864.57
Total heat-units derived from all kinds of food and from loss of body weight	32,938.05
Unaccounted for	38,926.52

Taking the heat produced by the body in maintaining the standard temperature for five days as 55,440.00, and the total heat-value of all kinds of food and of loss of body weight as 32,938.05, we have about forty per cent. of the heat produced which cannot be accounted for in the estimates that I have given. Adding to the heat produced by the body the estimated heat-units converted into force and used in walking 317½ miles and in keeping up circulation and respiration, we have a total of 71,864.57

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[1] Letheby, On Food, New York, 1872, p. 96.

[2] Haughton, Principles of Animal Mechanics, London, 1873, p. 57.

[3] A. Flint, Jr., The Source of Muscular Power, New York, 1878, p. 63.

heat-units, of which about fifty-five per cent. cannot be accounted for by the estimated heat-value of the food and of the loss of body weight.

These results are certainly most striking. It is admitted by those who adopt the theory that one heat-unit is equal to 772 foot-pounds, that in a machine, like a steam-engine, but a small fraction of the calculated value of the heat employed can be actually used or measured as force. As regards this fact, we are satisfied with the explanation that a large amount of heat is necessarily wasted. But suppose, instead of this, we burned coal in a steam-engine, the heat-value of which was equal to 12,000 heat-units, and produced thereby an amount of force (calculating that one heat-unit equals 772 foot-pounds) represented by 20,000 heat-units, leaving 8000 heat-units, or forty per cent. of the force actually produced, unaccounted for. In the face of such a demonstration, the theory that one heat-unit equals 772 foot-pounds would fall to the ground. Provided the experiments be correct, the same process of reasoning may properly be applied to the physiological problem. We start with the assumption that the oxidation of a definite amount of matter produces a definite amount of heat, be the process slow or rapid or be it in the animal machine or in a calorimeter. All food has a determinable heat-value. But the heat-value of the food compared with the amount of heat actually produced in the body in a given time leaves forty per cent. of the heat actually produced which cannot be accounted for. This large deficiency demonstrates the existence of some serious error which may be expressed in one or more of the following propositions:

1. There may be an error in calculating the heat-value of the articles of food.

2. It may be an error to assume that the heat-value of the changes which the food undergoes in the body is equal to the heat-value as calculated by experiments with the calorimeter.

3. There may be an error in the estimates of the amount of heat actually produced by the body.

If errors exist in any or in all of these propositions, they are very considerable.

Suppose, again, that we add to the heat used in maintaining the temperature of the body the heat-units converted into the force required for work. We have, of the heat-units required for all these processes, fifty-five per cent. unaccounted for. Added to the errrors to be looked for in reasoning from the animal heat alone and taking no account of the work, we have possible errors which may be expressed in the following propositions:

1. There may be an error in assuming that one heat-unit equals 772 foot-pounds.

2. Assuming that there is no error in the first proposition, it may be

incorrect to assume that the value of the transformation of one heat-unit into force in the body is equal to 772 foot-pounds.

3. There may be, and there probably is, a considerable error in the formula by which the work of walking on a level is reduced to foot-pounds.

4. There may be, and there probably is, a considerable error in the estimate of the force used in circulation and respiration.

Observation 2.—Nov. 22, 1878, I began the following experiment, in which I fasted for twenty-four hours:

Nov. 22*d.* 5.10 P. M., I had an alvine dejection. 6.45 P. M., I dined heartily. 10.45 P. M., I ate three poached eggs and toast and drank half a pint of Bass's ale. I slept well during the night.

23*d.* 7.45 A. M., I emptied the bladder but failed to have a passage from the bowels. 8 A. M., I began my observations, having taken no food since 10.45 P. M. of Nov. 22. My body-weight, without clothing, was $188\frac{1}{4}$ pounds. The temperature under the tongue, taken for five minutes, was 99° Fahr. I walked half a mile. 9 A. M., I drank 8 fluidounces of water. 10 A. M., I played at billiards for two and one-half hours and drank 8 fluidounces of water. 1.30 P. M., I walked a quarter of a mile. 2 P. M., hunger was quite distressing, but it was relieved by smoking. 3.30 P. M., I walked about a quarter of a mile. 4 P. M., I had hardly any sense of hunger. The temperature under the tongue, taken for five minutes, was $98\frac{5}{8}$° Fahr. 5.30 P. M., I played at billiards for one hour. 7.30 P. M., I drank 4 fluidounces of water. I went to the theatre in the evening and walked about a quarter of a mile. 11.15 P. M., the temperature under the tongue, taken for five minutes, was $99\frac{5}{8}$° Fahr. I slept rather uneasily during the night.

24*th.* 7.45 A. M., I emptied the bladder but could not secure an operation of the bowels. 8 A. M., the experiment was concluded. The body-weight, without clothing, was $184\frac{3}{4}$ pounds. The temperature under the tongue, taken for ten minutes, was $97\frac{3}{4}$° Fahr. I had fasted for about thirty-three hours, but I calculated the fast from 8 A. M., Nov. 23, to 8 A. M., Nov. 24, for twenty-four hours after digestion had probably been completed. I suffered from hunger only at about 11 A. M., 2 P. M., and 7 P. M., the hours when I habitually took food. The suffering from hunger was less than I had anticipated and was much relieved by smoking three cigars during the day, smoking very frequently and but little at any one time. It is proper to state that I am forty-two years of age, five feet ten and one-half inches in height, and that I have been in the habit of daily muscular exercise in a gymnasium for the past ten years. I have a rather unusual muscular development. The weather had been fair and partly cloudy, with a temperature of $45\frac{1}{4}$° Fahr., an average of eight observations.

The urine passed during the day was collected and analyzed, with the following results:

Total quantity, 34 fluidounces. Reaction acid; colour and odour normal; specific gravity $1023\frac{1}{2}$; no albumen; no sugar; nothing abnormal on microscopical examination.

An analysis of the urine was made by Dr. C. A. Doremus for urea and uric acid. The urea was estimated by Liebig's process, the standard solution having been carefully treated with pure urea. The uric acid was estimated by treating the urine for forty-eight hours with hydrochloric acid, all the corrections being carefully made. The results of these examinations were as follows:

Urea, 14.78 grains per fluidounce = 502.52 grains in twenty-four hours = 234.51 grains of nitrogen. Uric acid, 0.255 of a grain per fluidounce = 8.67 grains in twenty-four hours = 2.89 grains of nitrogen.[1]

The total quantity of nitrogen contained in the urea and uric acid eliminated in the twenty-four hours was 237.4 grains. It is estimated by Dr. Pavy, according to Frankland's observations, that one grain of urinary nitrogen is equivalent to an amount of nitrogenized tissue consumed which would produce 2.4355 foot-tons of force, or 7.067 heat-units.[2] The 237.4 grains of urinary nitrogen, therefore, would be equivalent to 1677.70 heat-units.

It is important, in following out the course of reasoning that I have attempted, to form an idea of the avenues of escape of the matter represented by the loss of body-weight during the twenty-four hours of abstinence from food. There was no passage from the bowels, and the loss of weight, therefore, must have taken place by the urine, skin, and lungs. The total loss of weight was 56 ounces. The water taken was 20 ounces, making 76 ounces. I passed 34 ounces of urine of a specific gravity of 1023½, the actual weight of which was 36 ounces.[3] This leaves an actual loss of weight, deducting the weight of the urine, of 40 ounces. This 40 ounces must have escaped by the lungs and skin in the form of carbonic acid and water. No account was taken, in the experiment, of the actual amount of carbonic acid eliminated, and this I was forced to estimate. It is stated by Dr. Edward Smith, as the result of observations upon four persons whose average weight was 160 pounds, that the total quantity of carbon eliminated in twenty-four hours was 7.144 ounces in a condition of perfect rest.[4] This is equivalent to about 8.327[5] ounces for a weight of 186½ pounds, which was the mean weight for the day. Deducting the estimated carbon eliminated from 40 ounces, we have an elimination of a little less than 32 ounces of water by the pulmonary and cutaneous surfaces. This is rather less than the estimates given in most works on physiology, but the difference is not very considerable.[6] Returning to the elimination of carbon, it is estimated that one ounce of dry fat contains 345.6 grains of carbon.[1] An elimination, therefore, of 8.327 ounces of carbon would represent 10.541 ounces of dry fat. According to Frankland,[2] the heat-value of 10.541 ounces of fat is equal to 10,759.09 heat-units.

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[1] I calculate the nitrogen by estimating that the proportion of nitrogen in urea is 0.466, and that the proportion of nitrogen in uric acid is one-third.

[2] The Lancet, Dec. 16, 1876, p. 849.

[3] A. Flint, Jr., Chemical Examination of the Urine, New York, 1878, p. 70, table.

[4] Edward Smith, Experimental Inquiries into the Chemical and other Phenomena of Respiration.—Philosophical Transactions, London, 1859, p. 692.

[5] In calculating the loss of weight by the lungs and skin, it is proper to estimate the weight of the carbon eliminated instead of the weight of the carbonic acid, for the reason that the carbon comes from the body and the oxygen which unites with it to form carbonic acid comes, at least indirectly, from the air. If we suppose that a certain quantity of the oxygen of the air unites with hydrogen to form water, which is thrown off, the weight of this oxygen should be deducted from the water; but experiments are wanting to show the amount of oxygen which combines in this way, and such a correction could not be made with any degree of accuracy.

[6] Valentin estimates the average pulmonary exhalation at about 19 ounces (A. Flint, Jr., Physiology of Man, New York, 1875, vol. i., p. 447). The estimate of the cutaneous transpiration is about 30 ounces (Ibid., vol. iii., p. 139). Taking into account the sea-

From these calculations we have, for twenty-four hours of fasting, the following sources of heat, which are capable of being estimated:

	Heat-units.
Heat-value of 237.4 grains of urinary nitrogen	1,677.70
Heat-value of 10.54 ounces of fat	10,759.09
Total	12,436.79

Estimating the heat produced by the body at four degrees per pound per hour, for a weight of 186½ pounds—

	Heat-units.
We have produced in twenty-four hours	17,904.00
Deduct	12,436.79
Unaccounted for by urinary nitrogen and carbon excreted .	5,467.21

If we assume that the estimate of the heat-value of the urinary nitrogen be correct as well as the heat-value of the probable exhalation of carbonic acid, and if we assume that the estimated heat produced by the body be reasonably accurate, a little less than one-third of the heat produced during the twenty-four hours of fasting cannot be accounted for by the heat represented by the urinary nitrogen and the carbon eliminated.

This experiment, in which absolutely no food was taken, possesses many points of peculiar interest and advantage. In such an experiment, we have but three matters discharged from the body, that demand serious consideration; viz., urinary nitrogen, carbonic acid, and water. We can calculate the amount of nitrogenized matter of the body represented by the urinary nitrogen and estimate its heat-value. We can also calculate the amount of fat represented by the carbonic acid discharged and estimate its heat-value. The only thing that remains is the water. From the estimates that have been made, there remain about 5500 heat units that cannot be accounted for by any heat-producing processes in the body represented by the amount of discharge of urea and carbonic acid. I have estimated that about 32 ounces of water are lost during the day by the lungs and skin. Of this 32 ounces, one-ninth, or 3.55 ounces, consists of hydrogen. It is estimated that one kilogramme of hydrogen will produce 34,600 heat-units C.,[3] and one pound, the same number represented in pounds, or 62,280 heat-units Fahr. The heat-value, then, of one ounce of hydrogen

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son of the year and the small amount of exercise and water taken, the estimate of 32 ounces for both the pulmonary and the cutaneous exhalation seems to be reasonable.

[1] Pavy, Food and Dietetics, Philadelphia, 1874, p. 440, quoted from Parkes.

[2] Letheby, On Food, New York, 1872, p. 94.

[3] Mayer, Celestial Dynamics.—Correlation and Conservation of Forces, New York, 1868, p. 261.

would be 3892.5 heat-units, or 13,818,375 heat-units for 3.55 ounces. If it could be shown that water is actually produced in the body by a union of hydrogen and oxygen, and that a sufficient quantity of oxygen is not returned to the air in the form of carbonic acid to combine with even one or two ounces of hydrogen, we could account, not only for the heat actually produced in the body, but for the heat assumed to be converted into force to carry on circulation, respiration, and any ordinary muscular work. There would be little difficulty in accepting such a theory of the source of heat and force produced, if it could be shown that the heat generated in the body exceeds the ordinary requirements; but when the number falls very far short, it seems impossible that the theory should be correct. The question here touched upon will be referred to farther on and discussed more fully.

Observation 3.—November 30, 1878, one week after the date of *Observation* 2, having entirely recovered from the effects of the previous experiment, I began the following observation, in which the quantity and the heat-value of food taken for twenty-four hours were carefully noted and calculated.

At 8 A.M., I had a passage from the bowels. The weight of the body taken just afterward, without clothing, was 186¼ pounds. The temperature under the tongue, taken for five minutes, was 98° Fahr.

At 8.45 A.M., I breakfasted as follows, taking each article from a separate plate, which was weighed before and after eating:

Lean beef-steak, 10 ounces, with bread, butter, and milk. The bread, butter, and milk were calculated for the twenty-four hours, and the bread-crum only was taken, without the crust.

At 1 P.M., I took a lunch of lean roast-beef, 6 ounces; boiled potatoes, 3.5 ounces, with bread-crum, butter, and milk.

At 5.30 P.M., the temperature under the tongue, taken for five minutes, was 99¾° Fahr.

At 6.45 P.M., I dined on lean roast-beef, 10 ounces; fried potatoes, 3 ounces; Bass's ale, 24.5 ounces by weight, with bread-crum and butter.

At 12, midnight, the temperature under the tongue, taken for five minutes, was 100° Fahr. I retired and slept well during the night.

At 8 A.M., December 1, I had a passage from the bowels. The body-weight taken just afterward, without clothing, was 186¼ pounds, exactly what it was at the beginning of the experiment. The temperature under the tongue, taken for five minutes, was 98¼° Fahr. During the twenty-four hours, I had taken 10 ounces of bread-crum, 3.75 ounces of butter, and 34.5 ounces of milk. The weather had been fine, with a temperature of 42⅞° Fahr., an average of eight observations. I had eaten of the articles indicated all that was possible. During the day, I walked about two miles, played at billiards for about three hours, and smoked five cigars. A calculation of the heat-value of the food was made by the following table reduced to ounces, from Letheby,[1] and carefully corrected from the original tables of Frankland:

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[1] Letheby, On Food, New York, 1872, p. 94.

Heat-units per Ounce Av. of the following Articles of Food oxidized in the Body.

Beef (lean)	160.12
Bread-crum	241.50
Potatoes	112.00
Butter	817.25
Milk	71.75
Bass's ale (alcohol reckoned)	87.06

According to this table, the following was the heat value of the food taken in the twenty-four hours:

	Heat-units.
Beef, 26 ounces	4,163.12
Bread-crum, 10 ounces	2,415.00
Potatoes, 6.5 ounces	728.00
Butter, 3.75 ounces	3,064.69
Milk, 34.5 ounces	2,475.37
Ale, 24.5 ounces	2,132.97
Total heat-value of food	14,979.15

Estimating the production of heat by the body as equal to four degrees per pound per hour—

	Heat-units.
We have produced in twenty-four hours	17,880.00
Heat-value of food	14,979.15
Unaccounted for by the heat-value of food	2,900.85

This calculation leaves about one-sixth of the heat produced by the body unaccounted for by the heat-value of the food taken.

Possible Oxidation of Hydrogen in the Body, resulting in the Formation of Water and the Production of Heat.—It is by no means a novel idea that oxygen may unite with hydrogen in the body to form water and produce heat;[1] but thus far there has been no experimental demonstration of the actual production of water in the animal economy. In the experiment in which I fasted for thirty three hours, for twenty-four hours of which no food was taken after the digestion of articles taken about nine hours before had been completed, I discharged about 32 ounces of water by the lungs and skin, and 34 ounces of water in the urine, making a total discharge of water of 66 ounces. During this period, I drank 20 ounces of water, leaving 46 ounces over and above the quantity taken. My loss of weight was 56 ounces, of which I estimate a loss of about ten ounces in solid matters in the urine and carbon by the lungs. The question now is whether this loss of 46 ounces of water was simply a discharge of water already formed, from the blood and the watery parts of the tissues, or whether it is to be attributed in part to water actually formed in the body by a union of oxygen and hydrogen. If the watery parts of the body be actually deficient in quantity, there is usually a sensation of thirst. I did not suffer from thirst, and, indeed, I drank rather more water than I desired.

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[1] In 1780 and 1785, Lavoisier and Laplace advanced the view that animal heat was produced by the oxidation of carbon and hydrogen in the body.

Recent experiments by Valentin, Panum, Colin, and others, have shown, in opposition to the previously received opinions, that abstinence from food has very little effect in diminishing the volume of the blood.[1] This fact, taken in connection with the absence of thirst during the twenty-four hours of fasting, is favourable to the view that all of the excess of water discharged did not come directly from the blood.

If water be actually produced in the economy by a union of oxygen and hydrogen, what is the probable source of these two elements? There is no deficiency of hydrogen in the body, and, if it be used to form water which is discharged, there would be loss of weight when no food is taken, and it would be supplied by the food under ordinary conditions of nutrition. There is no deficiency of oxygen in the body itself, and the oxygen discharged in urea represents only about one-third of the proportion of oxygen contained in the nitrogenized constituents of the body. Of the oxygen taken into the lungs, about 86 per cent. only is returned in combination with carbon to form carbonic acid, leaving 14 per cent. to form some other combination in the body, possibly a union with hydrogen. There is, indeed, little or no difficulty in accounting for the elements to form water in the body, if it can be shown that more water is discharged from the organism than is taken with the ingesta, and that the excess thus discharged does not come simply from the watery parts, producing an actual deficiency of water in the body.[2]

The actual demonstration that more water is ever discharged from the body than can be accounted for by the water of the ingesta or by water simply withdrawn from the blood rendering this fluid more dense, presents very considerable but not insurmountable difficulties. A process that would be open to few objections, provided all of the elements used in the calculations were accurate, is the one which I have attempted to employ in cases of loss of weight. This process is the following:

Take the weight of a man at the beginning of the experiment, calculate accurately the weight of the ingesta for a certain period, and add this latter to the weight of the body. This forms the sum total from which certain quantities are to be deducted. Take then the weight of the urine and feces passed during the time of the experiment; add to this the weight of the carbon contained in the carbonic acid exhaled, which carbon carries with it a portion of the inspired oxygen; add both of these to the weight of the body taken at the close of the experiment; the difference will give the amount of water discharged by the lungs and skin. Having thus the quantity of water discharged by the lungs and skin, to ascertain the total quantity of water discharged from the body, we have to add the water contained in the urine and feces. We then carefully estimate the amount of water contained in the ingesta and can compare the amount of water discharged with the quantity taken. In Pettenkofer's chamber, in which a man may be confined and all of the excreta be estimated, these calculations could be made with sufficient accuracy, and the only uncertain element in the problem would be as to whether or not the blood became modified in density or volume. In the following calculation, I was forced to estimate the amount of carbon eliminated; but I endeavoured to correct this estimate by an indirect method, which will be described farther on. The subject of my experiment was the person mentioned in *Observation* 1, and the investigations described were continued for five days. The following is a summary of the results:

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[1] Robin, Leçons sur les humeurs, Paris, 1874, p. 50.

[2] Funke, Lehrbuch der Physiologie, Leipzig, 1876, Bd. i., S. 297. I have quoted from Funke the results obtained by Pettenkofer and Voit, and have taken as an average of their results, 833 grammes of oxygen consumed and 985.2 grammes of carbonic acid produced in twenty-four hours. 985.2 grammes of carbonic acid represent 716.5 grammes of oxygen.

Observation upon the Ingress and Egress of Water.

		Ounces.
Body-weight at the beginning of the observation . .		1,907.20
Weight of the ingesta for five days		857.34
Total		2,764.54
Weight of the urine and feces for five days . .	220.47	
Carbon eliminated for five days, estimated at 10 ounces per day[1]	50.00	
Body-weight at the end of the five days (showing a loss of 55.2 ounces)	1,852.00	
	2,122.47	2,122.47
Water eliminated by the lungs and skin		642.07
Water contained in the urine and feces		208.89
Total water discharged		850.96

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[1] As I have stated in the text, I was forced to estimate the amount of carbon discharged, but I preferred to put it too high rather than too low. Ten ounces per day is a very high estimate for a man weighing 115½ pounds. The following indirect calculation of the probable sources of carbon shows that this estimate is certainly sufficient. I calculate the total carbon of the food as amounting to about 25 ounces. To this I add the carbon of 48 ounces of muscular tissue consumed (5.28 ounces), and of 7.2 ounces of fat, both loss of weight (5.69 ounces). This gives about 36 ounces of carbon for five days. From this I deduct 9 ounces of carbon discharged in the urea, which leaves 27 ounces for five days, or 5.4 ounces per day. If I calculated that the entire loss of weight of 55.2 ounces should be estimated as fat—which is very improbable from the condition of the subject on beginning the walk, and the discharge of a considerable quantity of nitrogen from the body over and above the nitrogen of food—we should have about 59 ounces of carbon for five days, or 11.8 ounces per day. The last-named quantity would make very little difference in the results.

Water of the Food for Five Days.

Articles of Food.	Quantity. Ounces.	Quantity Water. Ounces.
Meat	23.87	16.95
Eggs	27.60	17.31
Milk	36.03	31.34
Bread	28.87	12.70
Beef-essence	42.13	40.03
Oatmeal gruel	18.09	17.19
Potatoes	5.00	4.38
Butter	4.88	0.73
Coffee	287.09	278.48
Tea	124.25	1 3.01
Water	11.75	11.75
Lemonade	227.16	227.16
Molasses and water	4.40	4.18
Tomatoes	3.12	2.97
Sugar, salt, pepper, bicarbonate of potash	12.10	
	857.34	788.18
Total water discharged in five days		850.96
Total water ingested in five days		788.18
Excess of water discharged in five days		62.78
Excess of water discharged per day		12.56

The heat-value of the hydrogen required to form one ounce of water is equal to 432.5 heat-units. The heat-value, then, represented by the formation of 12.56 ounces of water would be 5432.2 heat-units.

During these five days, the subject of this experiment walked 317½ miles and lost 55.2 ounces in weight. As will be seen by reference to *Observation* 1, I have calculated the total heat produced by the body, the heat-units used in maintaining circulation and respiration and in walking 317½ miles. I then calculated, also, the heat-value of the food and of the loss of body-weight, the latter estimated as muscular tissue, taking no account of the hydrogen. According to this calculation, there remained 38,926.52 heat-units unaccounted for. If we take in addition the heat-value represented by the excess of water discharged for the five days, which is equal to 27,161.00 heat-units, we have 11,765.52 heat-units unaccounted for, which is about sixteen per cent. of the heat-units expended, instead of fifty-five per cent. However, in estimating the heat-units used in respiration, circulation, and walking 317½ miles, I have taken calculations that I regard as grossly erroneous; and I used them for sake of argument and without any confidence in their accuracy. The percentage of sixteen is probably not more than the error in the computation of the heat-units converted into force expended in maintaining circulation and respiration and in walking 317½ miles.

One of the observations in which I calculated the amount of water discharged as compared with the quantity ingested was for twenty-four hours of abstinence from food. (See *Observation* 2.) The other was for a person who lost considerable weight as the result of excessive muscular exertion. Even when no food is taken, a certain amount of heat must be produced, and the standard animal temperature must be maintained. The heat thus produced cannot be accounted for by the carbon discharged in carbonic acid, but it can be accounted for by the hydrogen discharged in water, and it seems reasonably certain that water is actually formed in the body. Under excessive exercise attended with loss of weight, it seems certain that water is produced in the body by a union of hydrogen and oxygen. Animal heat is undoubtedly produced very largely by oxidation; and it has been shown that muscular work, while it has a tendency to raise the animal temperature, very considerably increases the elimination of water.[1] The chemical products of this oxidation are represented mainly by urea, as far as nitrogen is concerned, by carbonic acid, and by water. There are thus three elements with which the oxygen combines; viz., nitrogen, carbon, and hydrogen. We cannot account for the total amount of heat produced in the body by the urea and carbonic acid discharged, but this can be accounted for by supposing that a certain quantity of hydrogen is oxidized in the body to form water.

I do not pretend to assert that the oxygen absorbed by the blood in its passage through the lungs forms a direct and immediate union with carbon and hydrogen to form carbonic acid and water. If such a union take place, carbonic acid and water are the final products resulting from a series of molecular changes, the various steps of which we are unable to follow; but it is probably true that, if a union of oxygen with carbon and hydrogen will produce a definite amount of heat, the quantity of heat is the same whether the combination be slow or rapid. As regards the oxidation of carbon and hydrogen, all that it is necessary to show is that carbonic acid and water are actually produced in the body, as a part of the final results of the intricate molecular changes involved in nutrition and disassimilation. There is no good reason to suppose that the processes of physiological wear or disassimilation of the tissues are radically changed in their character during a short period of abstinence from food, or during exercise which for a time wastes the tissues more rapidly than they can be repaired. When the appropriation of nutritive matters produces an equilibrium between the physiological waste and repair, it is logical to conclude that the waste of the tissues, which involves the oxidation of a certain quantity of carbon, nitrogen, and possibly hydrogen, is repaired by the food, the nature of the processes involved in the waste being the same as during a period of abstinence from food. As regards, therefore, the oxidation of hydrogen, we may suppose that the hydrogen of the non-nitrogenized parts is consumed, and that the matter thus consumed is supplied again to the tissues in order to maintain the physiological status of the organism.

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[1] Pettenkofer and Voit, as one of the conclusions arrived at by experiments upon a man 28 years of age, kept for twenty-four hours in their large respiration-apparatus, make the following statement: "The elimination of water is very much increased by work, and the increase continues during the ensuing hours of sleep." (Journal of Anatomy and Physiology, Cambridge and London, 1868, vol. ii. p. 181.)

The supposition that water may be actually formed within the organism under certain conditions not only completes the oxidation-theory of the production of animal heat, but it enables us to understand certain physiological phenomena that have heretofore been obscure. It is well known, for example, that a proper system of physical training will reduce the fat of the body to a minimum consistent with health and strength. This involves a diet containing a relatively small proportion of fat and liquids, and regular muscular exercise attended with profuse sweating. We have seen that muscular work increases the elimination of water, while it also exaggerates for the time the calorific processes. The muscular exercise undoubtedly favours the consumption of the non-nitrogenized parts of the body, and a diminution of the supply of hydrocarbons, carbohydrates, and water in the food prevents, to a certain extent, the new formation of fat. By taking an excessive quantity of liquids, we do not increase the calorific processes or promote activity of the circulation, and the excess of water is usually discharged by the kidneys. When, however, we exert the muscular system excessively, we increase the production of water and the circulation becomes more active. The volume of blood then circulating in the skin and passing through the lungs, in a given time, is relatively increased, and there is an increased discharge of water from these surfaces. The same condition that produces an increased quantity of water in the body and has a tendency to exaggerate the process of calorification seems to produce also an increased evaporation from the surface, which serves to equalize the animal temperature. It is stated by Mr. Maclaren, the author of an excellent work on training, that in one hour's energetic fencing, the loss by perspiration and respiration, taking the average of six consecutive days, was about three pounds, or, accurately, forty ounces, with a varying range of eight ounces.[1]

Conclusions.—I shall restrict the conclusions to be drawn from the experiments that I have described to points connected with the production of animal heat. It is undoubtedly true that, computing all of the force produced in the body as heat-units, more heat is generated than is absolutely necessary to maintain the normal animal temperature, and that a certain amount of this excess is manifested as force used in the work of respiration and circulation and general muscular effort. The computation of the force thus used is always made in accordance with the formula that one heat-unit is equivalent to 772 foot-pounds. The reduction of the force of the heart and the force exerted by the respiratory muscles to units of foot-pounds is so excessively difficult and uncertain that the estimates given by writers are, in my opinion, almost worthless. The same remark applies to the reduction of ordinary muscular work to definite units. Without some such reduction, the force exerted by muscles cannot be expressed in definite quantities. All that we can do is to show, if possible, that more heat-units are produced in the body than are required to maintain the heat of the body, and that a part of the excess is converted into force. I do not conceive that the simple experiment, which shows that one pound in falling 772 feet will produce heat enough to raise the temperature of one pound of water one degree Fahrenheit, proves absolutely that one heat-unit produced by burning food in oxygen, when the same food is oxidized in the body, making allowance for that which escapes such oxidation, can be converted into a muscular force equal to 772 foot-pounds.

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[1] Maclaren, Training, in Theory and Practice, London, 1866, p. 89.

The experiments which I performed were made under serious disadvantages. While it was not difficult to collect the urine and feces and to estimate the constitution of the food, I had no apparatus which would have enabled me to ascertain exactly the amount of oxygen absorbed and of carbonic acid exhaled for a number of hours. With such an apparatus as Pettenkofer's respiration-chamber, it would be possible to make an actual measurement of the quantity of oxygen absorbed and of carbonic acid and water excreted, and thus it might be shown whether or not water can be produced in the body; and, if it could be demonstrated that water can be thus produced, it could be ascertained what proportion of such water was probably produced by a union of a portion of the inspired oxygen with hydrogen, by simply deducting the oxygen used in the formation of carbonic acid from the total quantity consumed. Still, taking my experiments as they are, and connecting them with what had been previously ascertained with regard to the questions under consideration, I think I am justified in drawing from them the following conclusions:

1. It is probable, and, indeed, almost certain, that nearly all the animal heat is produced by oxidation, in the body, of certain elements, which are chiefly nitrogen, carbon, and hydrogen.

2. It is probable that this oxidation does not take place entirely in the blood, but that its seat is in the substance of the various tissues, and that it is connected with the general processes of nutrition and disassimilation. Heat is thus evolved, and the final products of the chemical actions involved are mainly urea, carbonic acid, and water. It must be remembered, however, that the oxidation is not necessarily a process identical with combustion out of the body, but that it is probably connected with a series of intricate molecular changes, which cease with the life of the tissues, and of which we are able to recognize only the final results; viz., calorification and certain chemical products.

3. Recognizing the products, urea, carbonic acid, and water, as representing probably the evolution of a certain amount of heat, we cannot

account for the heat actually produced in the body by the amount represented by the urea and carbonic acid discharged. If we admit that hydrogen is oxidized in the body, resulting in the evolution of heat and the production of water, this will enable us to account for all the heat actually manifested as heat, leaving an excess which may be converted into force.

4. My experiments show pretty clearly that, when no food is taken and when, food being taken, muscular work is performed, so that there is loss of body-weight, water is actually produced in the body. This, and this only, enables us to account for all the heat evolved under these conditions. There is no reason to suppose that the processes involved in the production of heat are radically changed in their character when enough food and water are taken to maintain a uniform body-weight.

5. Animal heat is produced mainly by oxidation of the nitrogen, carbon, and hydrogen of the tissues, the waste of these elements being supplied by the food. Probably the oxidation of carbon and hydrogen is a more important factor in calorification than the oxidation of nitrogen; at least it is certain that the heat-value of the oxidation of carbon and hydrogen is greater than that of the oxidation of nitrogen, and the quantity of heat thus produced is very much greater. Of the two elements, carbon and hydrogen, the oxidation of which produces animal heat, the heat-value of the hydrogen is by far the greater.

6. It is probable that there is always a certain amount of oxidation of hydrogen in the body, and that this is necessary to maintain the animal temperature; and it is almost certain that this occurs during prolonged abstinence from food and when the production of heat is much increased by violent and protracted muscular exertion. It may be, also, that there is an active and unusual oxidation of hydrogen as well as of carbon in fevers.

Alcohol, which is so extensively used as a measure of sustaining treatment in fevers, is now almost universally recognized as an element consumed in the body and not discharged to any considerable extent as alcohol. According to Brande,[1] Cognac brandy contains 46 per cent. of absolute alcohol. With a specific gravity of 0.930, one ounce of brandy weighs 406.875 grains and contains 187.1625 grains of alcohol. The alcohol, with a composition of $C_4H_6O_2$, contains 12.9 per cent. of hydrogen, or 24.14 grains, and 52.65 per cent. of carbon, or 98.54 grains. The heat-value of 24.14 grains of hydrogen equals 214.77 heat-units. The heat-value of 98.54 grains of carbon equals 182.44 heat-units.[2] Taking, then, the total heat-value of the hydrogen and carbon contained in one ounce of brandy, and taking no account of the oxygen contained, the heat-value amounts to 397.21 heat-units. If we assume that a man produces four heat-units per pound weight of the body per hour, the amount of heat normally produced in twenty-four hours by a man weighing 140 pounds is equal to 13,440 heat-units. The quantity of brandy required to supply this amount of heat, according to the calculations I have just made, would be a little less than 34 ounces. Theoretically, then, it is easy to see how alcohol may furnish material to supply heat and save waste of tissue in fevers. It is not very unusual, in certain stages of fever, to administer from 16 to 32 ounces of brandy in twenty-four hours.

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[1] Brande and Taylor, Chemistry, Philadelphia, 1867, p. 583.

[2] Mayer, Celestial Dynamics.—Correlation and Conservation of Forces, New York, 1868, p. 261.

I conclude this essay with the following query, which has occurred to my mind in connection with my reflections upon the question of the oxidation of hydrogen as one of the sources of animal heat:

If the excessive heat produced in essential fevers be due in part to an excessive oxidation of hydrogen, why would not the exhaustion and rapid emaciation which attend the progress of fever be more or less moderated by supplying hydrogen to the system in the form of fatty matters, starchy matters, sugar and alcohol, until the fever has run its course; and might not this supply, to a certain extent, the abnormal waste of tissue?

ARTICLE III.

CONTRIBUTIONS TO THE PATHOLOGY OF PERIPHERAL NERVE-DISEASES.

By JULIUS ALTHAUS, M.D., M.R.C.P., Senior Physician to the Hospital for Epilepsy and Paralysis, Regent's Park, London.

INFLAMMATION of the nerves is by some pathologists considered to be an extremely rare, and by other a more common affection. Dr. Weir Mitchell, an American physician to whom we owe an able monograph on injuries of nerves and their consequences, of which he saw numerous examples during the American civil war, considers acute idopathic neuritis an uncommonly rare disease; while Benedict, Remak, and others, appear to have enjoyed almost daily opportunities of meeting with such cases. My own experience leads me to believe that instances of this description are certainly more common than is generally supposed, and that although the evidence of post-mortem examinations is as yet not large, nevertheless the clinical symptoms are in many cases sufficiently striking to warrant the diagnosis of neuritis or perineuritis. One special affection of this class has recently been very closely investigated—I allude to optic neuritis, in which the changes going on in the nerve may be closely followed by the aid of the ophthalmoscope; and the observations made on this disease by Von Graefe in Germany, and Drs. Jackson, Clifford Allbutt, and others in this country, have thrown considerable light on its